

Extended Emission from Short Gamma-Ray Bursts Detected with SPI-ACS/INTEGRAL

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The short duration ($T_{90} < 2$ s) gamma-ray bursts (GRBs) detected in the SPI-ACS experiment onboard the INTEGRAL observatory are investigated. Averaged light curves have been constructed for various groups of events, including short GRBs and unidentified short events. Extended emission has been found in the averaged light curves of both short GRBs and unidentified short events. It is shown that the fraction of the short GRBs in the total number of SPI-ACS GRBs can range from 30 to 45%, which is considerably larger than has been thought previously.

Key words: short gamma-ray bursts, extended emission, afterglow.

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INTRODUCTION

Bimodality in the gamma-ray burst (GRB) duration distribution was discovered in a series of Konus experiments (Mazets et al. 1981) and was subsequently confirmed by extensive statistical data from the BATSE experiment (Kouveliotou et al. 1993), where a robust GRB duration parameter (T_{90}) was proposed (see the „Data Processing“ Section). The value of T_{90} , which separates the groups of GRBs, can depend on experiment ($T_{90} = 2$ s is used in BATSE). Long GRBs have a duration $T_{90} > 2$ s. Long GRBs have a softer spectrum than that of short ones; they also possess a spectral lag - the time profile in softer energy channels lags behind that in hard ones. Long GRBs are believed to result from the collapse of massive stars (see, e.g., Paczynski 1998). The nature of short ($T_{90} < 2$ s) GRBs has not yet been clarified completely. Theoretical studies showed that short GRBs could result from the mergers of compact objects (neutron stars or black holes) in binary systems (Paczynski 1986). This is confirmed by the absence of observational signatures of a supernova in the optical afterglow light curves of short GRBs. It is also speculated that there exist very short ($T_{90} < 0.1$ s) GRBs that constitute a separate class of events, along with the currently identified long and short GRBs, and that the evaporation of primordial black holes in the Galaxy could be the source of very short GRBs (Page and Hawking 1976; Cline et al. 2006).

Recently, one of the most distant GRBs has been detected, GRB 090423, with a redshift $z \sim 8.2$ and a duration in the observer’s frame of reference $T_{90} = 10.3$ s, but in the frame of reference associated with the GRB source, $T_{90} = 1.1$ s. It is unknown how this event should be classified, as a long or short burst, because the significant energy release (10^{53} erg) of this event is typical of long GRBs. Unfortunately, apart from its duration T_{90} , any additional information about a specific event (its energy spectrum, the source’s redshift, etc.) cannot always be obtained. Therefore, there exists an uncertainty in choosing a model of a specific event based only on its duration T_{90} in the observer’s frame of reference. One of the serious problems of a short event identification with a GRB is related to the existence of soft gamma repeaters whose light curves are very similar to those of GRBs (Mazets et al. 2008).

Extended emission (possibly, an afterglow) in the soft gamma-ray range (>25 – 50 keV) with a duration of more than 30 s (Table 1) was found in the averaged light curve of short GRBs in the BATSE (Lazzati et al. 2001; Connaughton 2002), Konus (Frederiks et

al. 2004), and BeppoSAX (Montanari et al. 2005) experiments. Extended emission with a duration of several tens of seconds was also found in the light curves of individual short GRBs ($T_{90} < 2$ s) in the Swift, BATSE, HETE-2, and Konus experiments (Burenin 2000; Norris and Bonnell 2006); the extended emission found in these experiments has a softer spectrum with respect to the main short episode, which is similar in its spectral properties to short bursts. A spectral lag is present in the light curves of several events with extended emission and such GRBs can be classified as long bursts. But the light curves of most „short“ GRBs with extended emission exhibit no spectral lag, for example, in the case of GRB 060614 (Gehrels et al. 2006): the duration T_{90} in the energy range 15-350 keV is 102 s; no signature of a supernova was found at the location of GRB 060614, although its distance is small ($z = 0.125$). The light curve of this event consists of a short hard episode with a duration of less than 5 s and a softer emission with a duration of ~ 100 s. There is no spectral lag in the light curve. Is this GRB long or short? Is extended emission a common property of short GRBs? What is the physics of the extended emission - is this emission an extension of the activity of the „central machine“ or this is the onset of an X-ray afterglow? In this paper, we attempted to answer these questions by investigating the short GRBs detected in a harder energy range (> 80 keV) with respect to previous studies of the extended emission with the anticoincidence shield (ACS) of the SPI spectrometer onboard the INTEGRAL observatory. We also compiled a catalog of confirmed short GRBs detected with SPI-ACS/INTEGRAL over the period 2002-2007, which complements and extends the catalog by Rau et al. (2005) containing data for 2002-2005 in the part of short GRBs.

DATA SELECTION AND PROCESSING

SPI-ACS INTEGRAL

SPI-ACS consists of a plastic scintillator PSAC, BGO crystals (bismuth germanate) of the upper and lower collimator rings and the lower protective shield; BGO crystals are also located in the side walls. The BGO crystals are viewed by photomultiplier tubes (PMTs) and the counts from all PMTs are recorded in a single channel. SPI-ACS records photons almost from all directions. The direction coincident with the SPI field of view, $30^\circ \times 30^\circ$, is least sensitive. SPI-ACS has a lower sensitivity threshold of ~ 80 keV - the physical properties of individual BGO assemblies (detector + PMT + discriminator)

slightly differ and have different lower thresholds from 60 to 120 keV; the upper threshold is ~ 10 MeV. The SPI-ACS time resolution is 50 ms (von Kienlin et al. 2003). SPI-ACS has a stable background level owing to the high elliptical orbit of the observatory. Although no spectral information can be obtained with SPI-ACS, the high upper sensitivity threshold and the field of view close to 4π make it a powerful instrument for investigating the class of hard short GRBs. SPI-ACS is part of IBAS (INTEGRAL Burst Alert System) (Mereghetti et al. 2003). The IBAS software algorithm selects events on nine different time scales (0.05, 0.1, 0.2, 0.4, 0.8, 1, 2, and 5 s), provided that the event significance with respect to the mean background is 9, 6, 9, 6, 9, 6, 9, and 6σ , respectively. The light curves of the events selected by this algorithm (containing data from -5 to 100 s relative to the trigger time) are publicly accessible (<http://isdcarc.unige.ch/arc/FTP/ibas/spiacs/>).

Catalog of Confirmed SPI-ACS GRBs

We partially used the catalog by Rau et al. (2005), which contains data on GRBs confirmed by other observatories: event date and time (UTC), significance, event duration T_{90} , fluence and peak flux on a 0.25-s scale. Apart from the data on confirmed GRBs, this catalog contains information about unconfirmed events that are candidates for GRBs. Such events were selected according to the following algorithm: each event selected by IBAS was checked for coincidence with the IREM (INTEGRAL Radiation Monitor, Hajdas et al. 2003) and GOES (Geostationary Operational Environmental Satellites, <http://www.sec.noaa.gov>) experiments in order to try to eliminate the events that result from the interaction of SPI-ACS with charged particle beams; the soft gamma repeaters (SGRs) were excluded; in addition, the event significance must exceed a 12σ threshold in the original SPI-ACS time resolution, 0.05 s. Thus, the catalog by Rau et al. (2005) contains data on 388 events detected from November 27, 2002, to January 12, 2005, among which only 179 events are confirmed GRBs. Events with a duration $T_{90} \leq 0.05$ s (0.05 s is the SPI-ACS time resolution) make the greatest contribution ($\sim 40\%$) to the group of unconfirmed short events. This group of events is described in more detail in the „Data Processing“ and „Discussion“ Sections. We compiled a catalog of confirmed short GRBs detected with SPI-ACS INTEGRAL from November 27, 2002, to January 23, 2008, (Table 2), which includes short bursts confirmed by other observatories. The confirmation search sources are the electronic GRBlog catalog (<http://grad40.as.utexas.edu/grblog.php>), which is a

full compilation of GCN circulars (<http://gcn.gsfc.nasa.gov/>) and IAU telegrams, and the master catalog by Hurley (2008) (<http://www.ssl.berkeley.edu/ipn3/masterli.txt>).

Data Processing

The catalog (Table 2) contains data on the 83 confirmed GRBs with a duration $T_{90} < 2$ s detected with SPI-ACS/INTEGRAL over the period 2002–2007, which complements and extends the catalog by Rau et al. (2005) in the part of short bursts. We selected 53 light curves to construct an averaged light curve, because the full light curves for the remaining events were inaccessible either due to their being not public or due to the stopping of telemetry because of the observatory’s slew. These GRBs constitute the first group of investigated events. The second group consists of short bursts unconfirmed by other space observatories, candidates for GRBs from the catalog by Rau et al. (2005) with a duration $T_{90} < 2$ s (105 events). The third group is a subset of the second group - this includes short unconfirmed candidates for GRBs from the catalog by Rau et al. (2005) with a duration $T_{90} \leq 0.05$ s (43 events).

As was shown by Rau et al. (2005), there exists a class of short events with a duration $T_{90} \leq 0.05$ s detected with SPI-ACS that has the following property: saturation, the absence of any signal for several (up to several tens) seconds, is observed in one or more neighboring SPI germanium detectors simultaneously with the short burst in SPI-ACS. The light curve for one of such events is shown in Fig. 1. It is suggested (Rau et al. 2005) that this class of events is related to the interaction of the SPI-ACS and SPI detectors with charged particles. The fourth, test group consists of such events (the first, second, and third groups contain no such events).

All light curves were aligned relative to the main peak using a procedure similar to that proposed by Mitrofanov et al. (1996) (as an example, Fig. 2 shows the light curve of GRB 060221) and were investigated in the time interval $[-150; 200]$ s. The processing procedure consists of the following steps:

(1) Background model approximation. The background variations on various scales were investigated: we grouped the bins with a time resolution of 50 s, as shown in Fig. 3 for revolution 405 of the observatory, and calculated the maximum background changes on a time scale of 350 s corresponding to the interval in which the light curves of all the events being analyzed were investigated. It follows from Fig. 3 that the behavior of the background

is monotonic on the 350-s time scale. Therefore, we used a linear background model in the intervals $[-150; -50]$ and $[100; 200]$ s relative to the main peak. We also established that the background in the 350-s time interval changed by no more than 0.3%. In an absolute majority of cases, the model describes well the background behavior. However, in several cases, the quality of the linear model fit was unsatisfactory and these events were excluded from further consideration. Our analysis of the background variance confirmed the deviation of the statistical signal distribution from a Poisson law — the 1σ significance of the signal above the background B is determined from the formula $1.57 \times B^{1/2}$, which independently confirms the papers by von Kienlin et al. (2003) and Ryde et al. (2003). All the subsequent calculations of the standard deviations take this fact into account.

(2) Background model subtraction from the light curve.

(3) Calculation of the event duration T_{90} (the time in which 90% of the burst energy is emitted). The algorithm for calculating T_{90} is discussed in Koshut et al. (1996). Figure 4 presents the scheme for calculating T_{90} for GRB 030325. An integral light curve of the event is constructed. Subsequently, the numbers of counts corresponding to 5% and 95% of the total number of counts (indicated in Fig. 4 by the horizontal solid lines) are determined. Next, the times T_5 and T_{95} (vertical solid lines) corresponding to these fluxes are found and their difference, which is the duration $T_{90} = 2.00 \pm 0.15$ s, is calculated. The values of T_{90} we calculated were compared with those from Rau et al. (2005) and with the values published for the same events but determined in different experiments: the durations in the RHESSI experiment were taken from Ripa et al. (2009), in the Suzaku experiment from the catalog at <http://www.astro.isas.jaxa.jp/suzaku/HXDWAM/WAM-GRB/>, in case of the Swift experiment from Sakamoto et al. (2008), and, in the remaining cases, from GCN circulars. These values are also given in Table 2. No significant differences in durations were found.

(4) Grouping of bins — increasing the bin duration from 0.05 to 5 s. Figure 5 shows the result of processing the light curve for GRB 060221.

(5) Averaging. The light curves of all GRBs aligned relative to the main peak and processed according to the procedure described above were averaged (the light-curve points corresponding to the same time in different light curves were averaged). In the individual light curves of GRB 060221 (Fig. 5) and GRB 031214 (Fig. 6) after the processing procedure described above, we found statistically significant extended emission with a

duration of ~ 50 and ~ 20 s (T_{90} for these events are 0.2 and 0.3 s, respectively), with the extended emission from GRB 031214 having been also found in the Konus experiment (Oleynik et al. 2008). These two GRBs were excluded from the subsequent analysis.

As has already been noted in the Introduction, it is often impossible to determine whether a GRB belongs to the class of short or long bursts based only on its light curve. Studies of the event spectrum, analysis of the lag in various energy channels, and a recently proposed method for burst separation in Amati’s $E_p - E_{iso}$ diagram (Amati 2010) are needed for the most comprehensive analysis. There is no clear boundary in the duration distribution either and the boundary $T_{90} = 2$ s was chosen by analogy with BATSE. Therefore, events belonging to the class of long bursts can also be present in the sample of bursts. The number of such events can be estimated from the lognormal distributions that describe a bimodal duration distribution. For BATSE, such estimation for the 2-s boundary gives 2%. A more accurate determination of the boundary is discussed, for example, in Donaghy et al. (2006).

In the averaged light curves for the first and second groups of short events (51 and 105 events, respectively), we also found extended emission with a duration of ~ 25 s (Minaev et al. 2009). Figure 7 presents the light curves of confirmed and unconfirmed short events (the first and second groups of GRBs). Since extended emission was found in the averaged light curve of short GRBs in various experiments (SPI-ACS/INTEGRAL, BATSE, Konus, BeppoSAX), it can be assumed that this is an actually existing phenomenon. From the available data for short GRBs, we can draw only statistical conclusions based on the averaging of various samples (confirmed and unconfirmed GRBs). We cannot assert that extended emission is a property of each short GRB. Nevertheless, the extended emission found in the averaged light curve of unconfirmed short events suggests that some of the *unconfirmed* short events belong to the class of real GRBs. For an independent test, we selected short events associated with triggers from charged particles (the fourth group of GRBs). There is no extended emission in the averaged light curve of 33 such events (Fig. 8). Consequently, we have no reason to reject the assumption that some of the unconfirmed short events are real GRBs.

DISCUSSION AND CONCLUSIONS

In the averaged light curve for the first group of short events (confirmed GRBs), we

found extended emission with a duration of 25 s and an intensity of (46 ± 15) counts/s (Fig. 7). Thus, extended emission can be assumed to be a common property of all short GRBs: it was found in the averaged light curve of the short GRBs detected in various experiments (see Table 1). The extended emission found in the averaged light curve of unconfirmed short events (the second group) suggests that some of the events from this group also belong to the class of real GRBs and not to triggers from charged particles and that the total fraction of the short GRBs is considerably higher than has been thought previously. If the intensity of the extended emission is assumed to be the same for all short GRBs, then the number of real short GRBs in the group of unconfirmed events can be estimated from the intensity of the extended emission in the averaged light curves. Thus, the fraction of the real GRBs in the group of unconfirmed events is $(84 \pm 35)\%$.

The fraction of the short GRBs detected in BATSE is $\sim 25\%$ of all the detected GRBs (Kouveliotou et al. 1993), their fraction in the APEX experiment is $\sim 38\%$ (Kozyrev et al. 2004), and the fraction of the short GRBs detected with SPI-ACS/INTEGRAL and confirmed by other space observatories is 16%. If all unconfirmed short events (the second group) are assigned to the class of real GRBs, then the total fraction of the short GRBs detected with SPI-ACS/INTEGRAL will be $\sim 45\%$, which is the upper limit for the number of short GRBs in the SPI-ACS experiment. The lower limit is 30% under the assumption that the fraction of the real GRBs in the group of unconfirmed events is 84%.

Since the lower energy threshold for BATSE triggers (for most part of the mission ~ 50 keV) is lower than that for SPI-ACS, the fraction of the harder short events detected with SPI-ACS is more than 25%. This is an additional argument for the hypothesis that some of the unconfirmed short events are real cosmic GRBs. The smallest trigger windows (the time intervals in which the signal is compared with the background value) for BATSE and SPI-ACS are approximately the same, 64 and 50 ms, respectively. It is also interesting to estimate the sensitivity of SPI-ACS to short events and to compare it with the corresponding sensitivity of BATSE. Vigano and Mereghetti (2009) discuss the conversion of SPI-ACS counts to energy units: for a normal angle between the source and the X axis of the INTEGRAL observatory, 1 SPI-ACS count corresponds to 10^{-10} erg cm $^{-2}$. Taking into account the mean background value in SPI-ACS and the trigger algorithm, we will find that the sensitivity of SPI-ACS to short events is $\sim 6 \times 10^{-8}$ erg cm $^{-2}$ and $\sim 1.7 \times 10^{-7}$ erg cm $^{-2}$ on time scales of 50 ms and 1 s, respectively. The sensitivity of BATSE on a time scale of 1 s is $\sim 10^{-7}$ erg cm $^{-2}$ (Fishman et al. 1994).

To investigate the extended emission, we fitted the averaged light curve for the combined first and second groups of events by functions $y = at^b$ and $y = ce^{dt}$ in the segment $[0; 40]$ s relative to the main peak with a time resolution of time profile of 5 s. Figure 9 presents the signal significance for the combined groups. To estimate the likelihood of these models, we used the χ^2 test. The values obtained (with six degrees of freedom) are 11.8 and 16.2 for the first and second models, respectively. Consequently, the significance that the extended emission is described by these models is low, no more than 7% and 1%, respectively. The power-law model of the extended emission cannot be rejected, while the exponential model describes the behavior of the extended emission considerably more poorly, which probably rules out the FRED model of the extended emission. On the other hand, since the extended emission was found in a hard energy range (≥ 80 keV), the extended emission found can be assumed to be an extension of the activity of the GRB central machine rather than the onset of an X-ray afterglow.

In the averaged light curve for the third group of events (unconfirmed short GRBs with a duration $T_{90} \leq 0.05$ s), we also found extended emission with a duration of 125 s and a total intensity of (213 ± 35) counts/s (Fig. 6). This suggests that the nature of „very short“ GRBs is probably the same as that of „ordinary“ short GRBs with a duration $T_{90} \leq 2$ s (the group of very short GRBs is studied in more detail in Minaev et al. (2010)). However, it is speculated (Cline et al. 2006) that very short GRBs result from the evaporation of hypothetical primordial black holes. The light curve corresponding to the evaporation of a primordial black hole consists of a very short episode whose duration is fractions of a second (Cline et al. 2006; Petkov et al. 2008) and no extended emission must be observed from such events. Therefore, the very short GRBs detected with SPI-ACS/INTEGRAL probably should not be assigned to the class of events related to the evaporations of primordial black holes. There is no extended emission in the averaged light curve for the test, fourth group of events (triggers from charged particles) (Fig. 8).

For the groups being investigated, we constructed a cumulative $\log N - \log C_{max}$ distribution (Fig. 10), where N is the number of bursts with a count rate at the light-curve maximum exceeding C_{max} . The deviation from uniform distribution of sources in 3D Euclidean space of the curve for the first group of events (confirmed short GRBs from our catalog) at low values of C_{max} can be attributed to the selection effect: the low-intensity events are missed. The curve for the sample of unconfirmed GRBs is closest to the uniform distribution of sources in Euclidean space (the „-3/2 law“). Therefore, if the unconfirmed

short GRBs are assumed to have the same nature as that of the confirmed ones, then the overall $\log N - \log C_{max}$ distribution will satisfy the -3/2 law. This corroborates the present views of the spatial distribution of short GRBs as objects of the close Universe ($z < 1$, Gehrels 2008).

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Table 1. Extended emission in the averaged light curve of short GRBs

Experiment	Energy range, keV	Number of investigated GRBs	Emission duration, s
BATSE	25-110	76	100 ¹
BATSE	50-300	100	100 ²
Konus	10-750	125	100 ³
BeppoSAX	40-700	93	30 ⁴
INTEGRAL	> 80	53	25 ⁵
INTEGRAL	> 80	43	125 ⁶

¹ - Lazzati et al. (2001).

² - Connaughton (2002).

³ - Frederiks et al. (2004).

⁴ - Montanari et al. (2005).

⁵ - This paper, the first group of events.

⁶ - This paper, the third group of events.

Table 2. Catalog of confirmed short GRBs detected with SPI-ACS/INTEGRAL.

GRB	Trigger time, UT	T_{90} , s	C_{max} , 10^3cnts	Confirmation ¹	T_{90} , s ⁽²⁾	Comm.
030101	20:43:32	0.7 ± 0.1	1.9 ± 0.1	u, h, k	1.0[1]	+
030105	14:34:12	$1.2 \pm 0.15^{**}$	3.7 ± 0.1	m, k, r	1.23[2]	+
030109	9:37:37	0.35 ± 0.1	0.6 ± 0.1	u		+
030110	9:39:28	0.1 ± 0.05	1.3 ± 0.1	k		+ sl. ³ (130s) ⁴
030117	17:36:14	0.15 ± 0.05	3.7 ± 0.1	k		+
030217	23:31:42	0.35 ± 0.05	4.1 ± 0.1	m		+
030325	14:15:11	2 ± 0.15	2 ± 0.1	u, k, m	2.0[3]	+
030523	14:10:52	0.15 ± 0.05	1 ± 0.1	k, r	0.12[2]	+
030607	2:19:21	0.1 ± 0.05	-	k		sl.
030629	3:26:39	0.15 ± 0.05	3.1 ± 0.1	k		+ sl. (-95s)
030711	0:04:01	0.25 ± 0.05	-	m		sl.
030717	20:49:24	0.05 ± 0.05	4.1 ± 0.1	u	0.06[4]	bad bgd. ⁵
030916	21:59:18	0.65 ± 0.1	1 ± 0.1	k		+
030926	16:52:27	0.2 ± 0.05	0.6 ± 0.1	r, h, m, k	0.28[2]	+
030929	14:27:14	0.45 ± 0.05	-	k		sl.
031026	1:26:29	0.25 ± 0.05	2.3 ± 0.1	m, k		+
031208	1:18:28	2.0 ± 0.5	-	k		sl.
031210	11:51:06	0.7 ± 0.1	0.4 ± 0.1	k		+
031214	10:10:50	0.3 ± 0.05	59.9 ± 0.4	k, m	0.3[5]	ext. em. ⁶
040202	13:29:52	0.4 ± 0.05	2 ± 0.1	u		+
040312	0:02:35	0.3 ± 0.1	2.9 ± 0.1	k, r	0.16[2]	+
040322	7:29:02	0.1 ± 0.05	-	k, m	0.19[6]	sl.
040324	10:21:10	0.2 ± 0.05	11.7 ± 0.2	k, r	0.26[2]	+
040329	11:10:49	2 ± 0.05	14.3 ± 0.2	k, r	2.07[2]	+
040417	8:05:09	1.25 ± 0.1	0.4 ± 0.1	k		+
040802	18:02:20	1.1 ± 0.3	0.5 ± 0.1	h, m, k		+
040822	21:21:53	0.55 ± 0.1	0.9 ± 0.1	k, r	1.38[2]	+
041013	22:56:26	0.35 ± 0.05	2.2 ± 0.1	m, k, r	0.36[2]	+
041116	14:42:41	1.1 ± 0.15	1 ± 0.1	h, k	0.5[7]	+
041213	6:59:36	0.1 ± 0.05	2.9 ± 0.1	k, r	0.14[2]	+ sl. (100s)
050111	6:52:26	0.1 ± 0.1	0.9 ± 0.1	k, h		+
050112	11:10:23	0.45 ± 0.05	17.9 ± 0.2	k, h	0.52[8]	+
050212	21:24:12	0.2 ± 0.05	6.9 ± 0.2	k		+
050216	7:26:34	0.3 ± 0.05	2.9 ± 0.1	r, k	0.5[2]	+

Table 2. (Contd.)

GRB	Trigger time, UT	T_{90} , s	C_{max} , 10 ³ cnts.	Confirmation	T_{90} , s	Comm.
050328	3:25:14	-	-	k, r	0.45[2]	sl.
050409	1:18:35	1.15 ± 0.1	10.6 ± 0.2	m, k, r	1.26[2]	+
050502	19:56:55	1.05 ± 0.05	0.4 ± 0.1	r	1.6[2]	+ sl. (185s)
050513	4:39:59	0.8 ± 0.1	1.3 ± 0.1	k, m, mes		+
050724	12:34:09	0.75 ± 0.15	0.9 ± 0.1	k, s	0.25[9]	+
050805	13:29:47	0.45 ± 0.05	2.8 ± 0.1	r, k, m	1.05[2]	+
050809	20:15:24	1.35 ± 0.15	1.5 ± 0.1	r, k, m	2.4[2]	+
050821	10:55:41	0.2 ± 0.05	1.9 ± 0.1	k, sz	2.0[10]	+
051016	5:19:37	$1.05 \pm 0.05^*$	-	k		sl.
051107	2:30:41	-	-	k, s ⁷ , sz	1.75[11], 5[10]	sl.
051221	1:51:15	0.25 ± 0.05	9.1 ± 0.2	m, r, s, sz	0.28[2], 1.4[12], 0.5[10]	+ +
060103	8:42:47	0.9 ± 0.1	0.8 ± 0.1	m, k		+
060126	9:30:04	0.15 ± 0.05	1.9 ± 0.1	h, r		+
060130	6:10:52	-	-	k, r, sz	0.41[10]	bad bgd.
060221	21:14:58	0.2 ± 0.15	0.8 ± 0.1	sz	0.75[10]	ext. em.
060303	22:42:47	0.35 ± 0.05	9.5 ± 0.2	k, s ⁷ , sz, r	0.38[10], 0.5[2]	+
060306	15:22:39	0.85 ± 0.05	64.1 ± 0.4	k, r, s ⁷	0.92[2]	+ sl. (-90c)
060312	6:17:20	0.6 ± 0.3	0.6 ± 0.1	r, s ⁷ , sz	3[10], 0.24[2]	+
060313	0:12:06	0.7 ± 0.05	6.4 ± 0.2	m, k, s	0.74[12], 0.8[13]	+
060425	16:57:37	-	-	s ⁷ , sz, r	0.14[2], 0.19[10]	sl.
060427	23:51:55	-	-	m, k, s ⁷	0.2[14]	sl.
060429	12:19:51	0.1 ± 0.05	11.9 ± 0.2	m, k, r, sz	0.2[2], 0.13[10]	+
060601	7:55:39	-	-	sz	0.5[10]	sl.
060610	11:22:24	0.65 ± 0.05	2 ± 0.1	m, k, r, sz	0.69[10], 0.6[2]	+
060823	8:05:33	1.05 ± 0.05	0.7 ± 0.1	sz, r	1.0[2], 2.0[10]	+
060912	18:31:01	-	-	sz	0.5[10]	n/d ⁸
060916	14:33:34	-	-	sz	0.13[10]	n/d
061001	21:14:28	$0.85 \pm 0.65^*$	-	s ⁷		n/d
061003	12:14:20	$0.85 \pm 0.05^*$	-	k, s ⁷		n/d
061006	16:45:28	0.45 ± 0.05	2.2 ± 0.1	k, r, s, sz	0.44[10], 0.4[2], 129.9 [12] ⁹	+
061006	8:43:36	1.65 ± 0.05	2 ± 0.1	m, k, r, s ⁷ , sz	1.6[10], 1.65[2]	+
061014	6:17:02	1 ± 0.05	2.1 ± 0.1	r, sz	1.2[10], 0.2[2]	+
061021	18:29:24	1.1 ± 0.1	0.5 ± 0.1	k		+

Table 2. (Contd.)

GRB	Trigger time, UT	T_{90} , s	C_{max} , 10^3 cnts.	Confirmation	T_{90} , s	Comm.
070113	11:56:23	-	-	k, r, sz	0.23[10], 0.27[2]	n/d
070129	22:09:25	-	-	k, s ⁷ , sz	0.22[10]	n/d
070203	23:06:44	-	-	sz	0.69[10]	n/d
070321	18:52:15	0.4 ± 0.05	0.7 ± 0.1	sz, s ⁷ , k, m	0.34[10]	+
070413	20:37:55	-	-	sz	0.19[10]	n/d
070516	20:41:24	-	-	k, r, s ⁷ , mes, sz	1.0[10], 0.35[2]	n/d
070713	13:08:37	$0.55 \pm 0.2^*$	-	k, s ⁷		n/d
070721	14:24:09	$0.9 \pm 0.25^*$	-	m, k		n/d
070915	8:34:48	$0.65 \pm 0.05^*$	-	k, s ⁷ , mes		n/d
070921	9:47:54	$1.25 \pm 0.50^*$	-	sz	2.7[10]	n/d
070927	22:25:20	0.8 ± 0.3	0.5 ± 0.1	m		+
070927	16:27:55	0.25 ± 0.15	1.4 ± 0.1	r, s ⁷ , mes, sz		+
071112	18:23:31	-	-	s, sz	1.0[10], 1.0[15]	n/d
071227	20:13:47	-	-	k, s, sz	1.8[16]	n/d
080121	21:29:55	-	-	s	0.7[17]	n/d
080123	4:21:57	-	-	k, s, sz	0.4[18]	n/d

Notes.

* The values were obtained from public IBAS data, i.e., in the time interval [-5; 100] s relative to the trigger time.

** Ryde et al. (2003) gives a duration of 13 s for this burst. In other sources, the burst duration is 0.9 s (Rau et al. 2005) and 1.3 s (Ripa et al. 2009).

In the standard analysis performed in our paper, we found no statistically significant extended emission in the SPI-ACS energy range. A joint analysis of the duration and hardness of this burst in the RHESSI experiment (Ripa et al. 2009) allows it to be classified as a short/hard burst with the possible presence of extended emission.

+ Used in the averaged light curve.

¹ The observatories that also detected this event: u - Ulysses, h - HETE-2, k - Konus, s - Swift, mes - Messenger, sz - Suzaku, r - RHESSI, m - Mars-observer.

² The durations determined in other experiments, the number of the corresponding reference at the end of Table 2 is given in square brackets.

³ The data for the corresponding event are inaccessible due to the observatory's slew (hereafter, „sl.“).

⁴ The final (or initial) time in the available light curve (relative to T_0) used for averaging is specified.

⁵ The light curve was excluded from the averaged light curve due to an unsatisfactory background fitting quality (hereafter, „bad bgd.“).

⁶ A short GRB with detected extended emission (hereafter, „ext. em.“).

⁷ This event was observed outside the BAT/Swift field of view.

Table 2. (Contd.)

⁸ The original data for the corresponding event are inaccessible (hereafter, „n/d“).

⁹ The duration of this event is 120 s in the range 15–100 keV and 0.58 s at >100 keV (Lin et al. 2008), the burst consists of a short hard peak and a period of activity in the soft energy range. This burst was initially classified as a short/hard one (Krimm et al. 2006). In our standard analysis, we found no extended emission from GRB 061006 in the SPI-ACS energy range and also classify it as a short burst.

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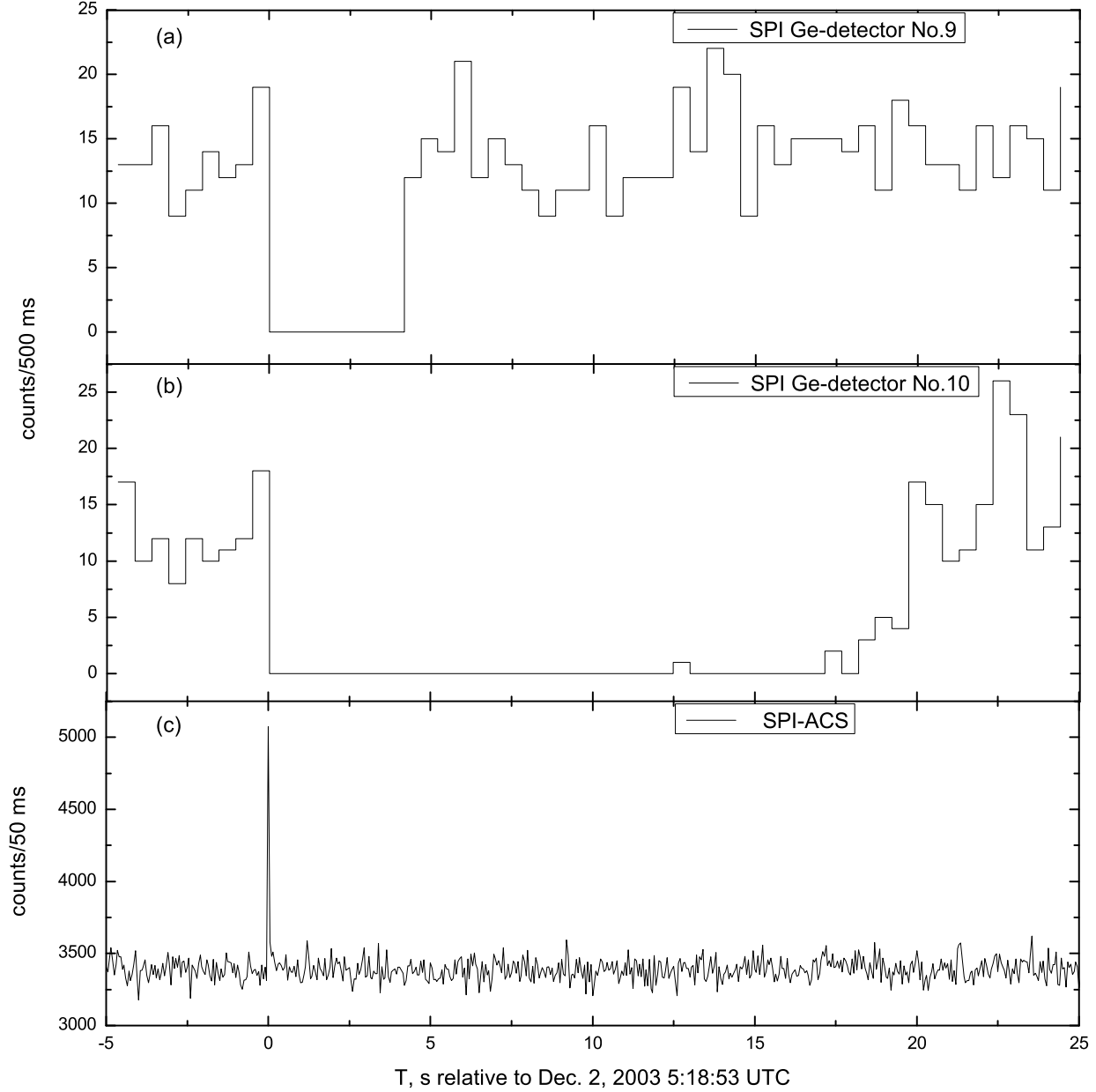


Fig. 1. Example of a very short SPI-ACS event (c) with simultaneous saturation of two SPI germanium detectors (a, b). The SPI-ACS light curve is presented with the original time resolution of 50 ms; the light curves of the SPI germanium detectors no. 9 and no. 10 are presented with a time resolution of 500 ms.

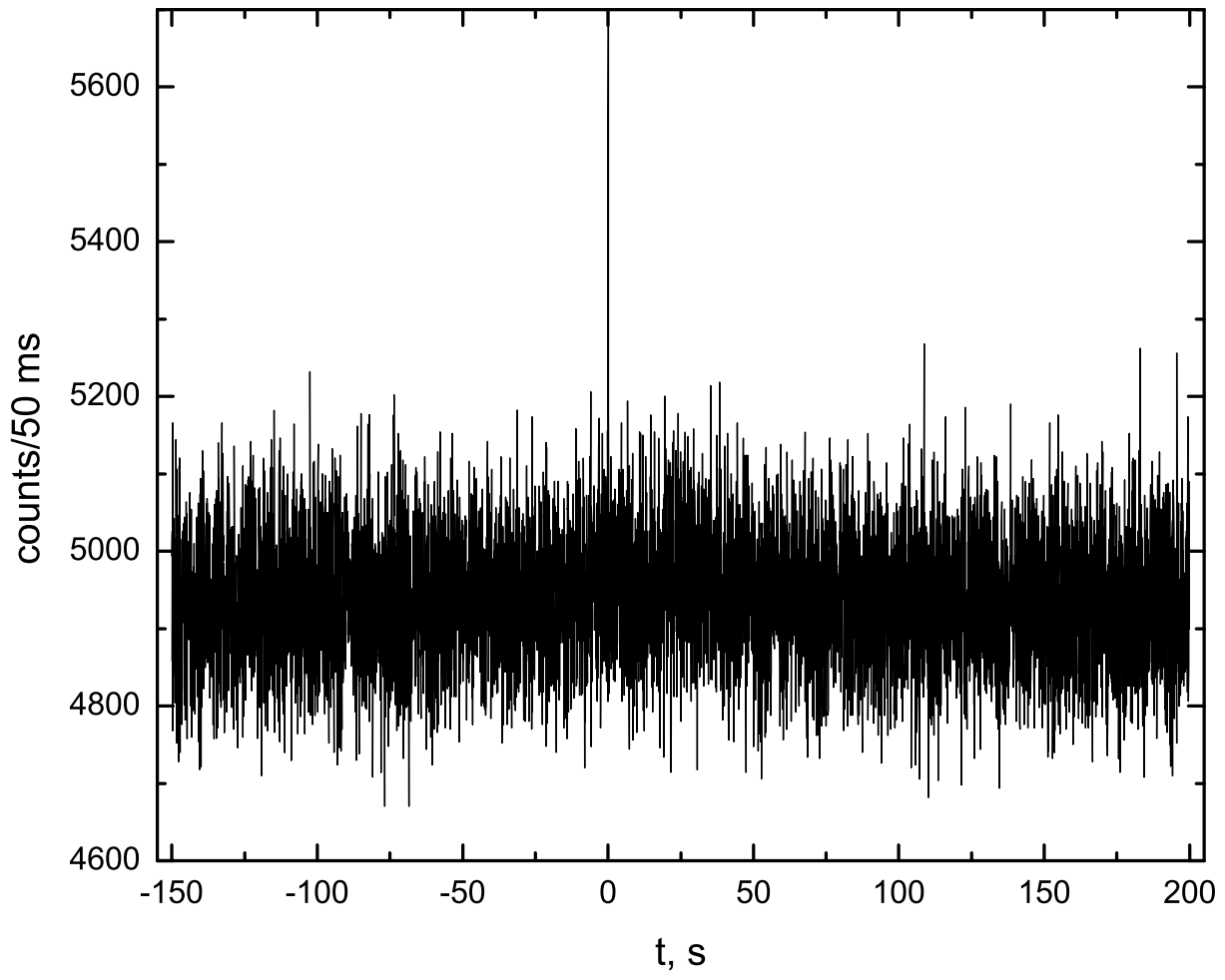


Fig. 2. Light curve of GRB 060221 with the original SPI-ACS time resolution of 50 ms. Time relative to the trigger T_0 is along the horizontal axis.

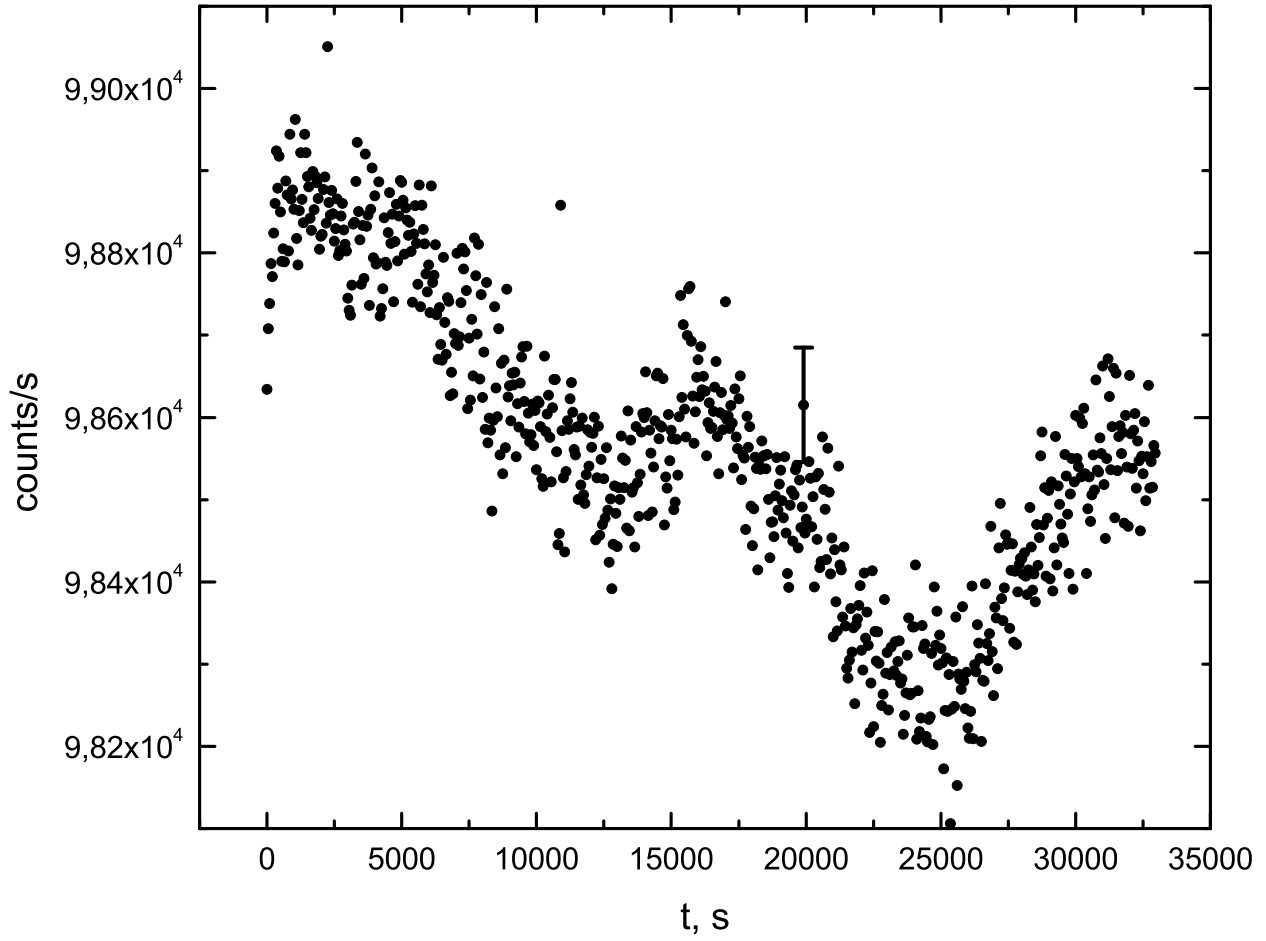


Fig. 3. Behavior of the background on long time scales (revolution 405). Time relative to the SPI-ACS switch-on after the passage through radiation belts is along the horizontal axis. A 1σ significance is shown for one point.

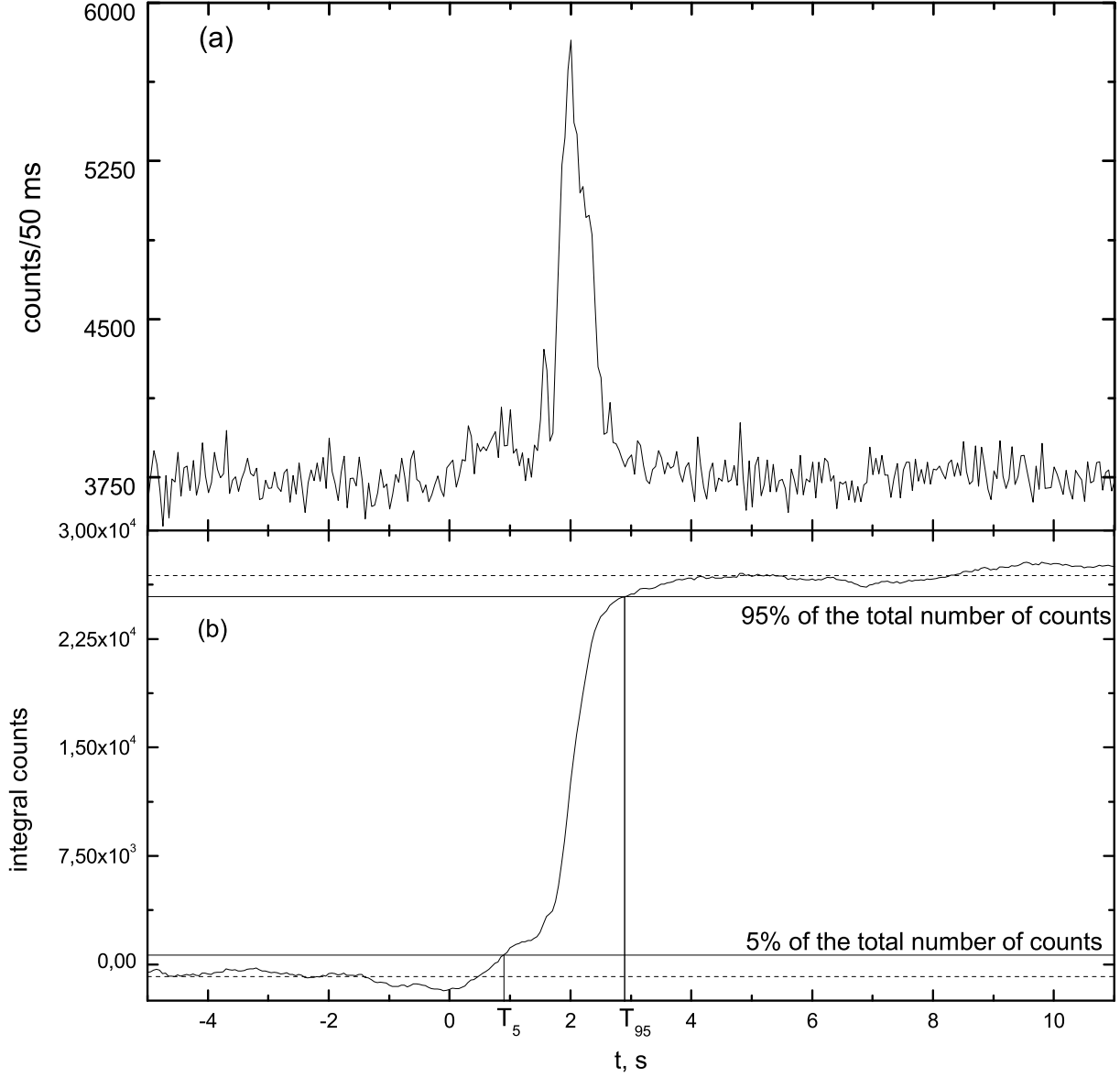


Fig. 4. Scheme for calculating the duration of GRB 030325: (a) the light curve with the original time resolution of 50 ms, the number of counts in 50 ms is along the vertical axis; (b) the corresponding integral light curve, the integral number of counts after the background subtraction is along the vertical axis. The horizontal dotted lines indicate 0 and 100% levels of the total number of GRB counts and the solid lines indicate 5 and 95% levels. The corresponding values of T_5 and T_{95} are shown.

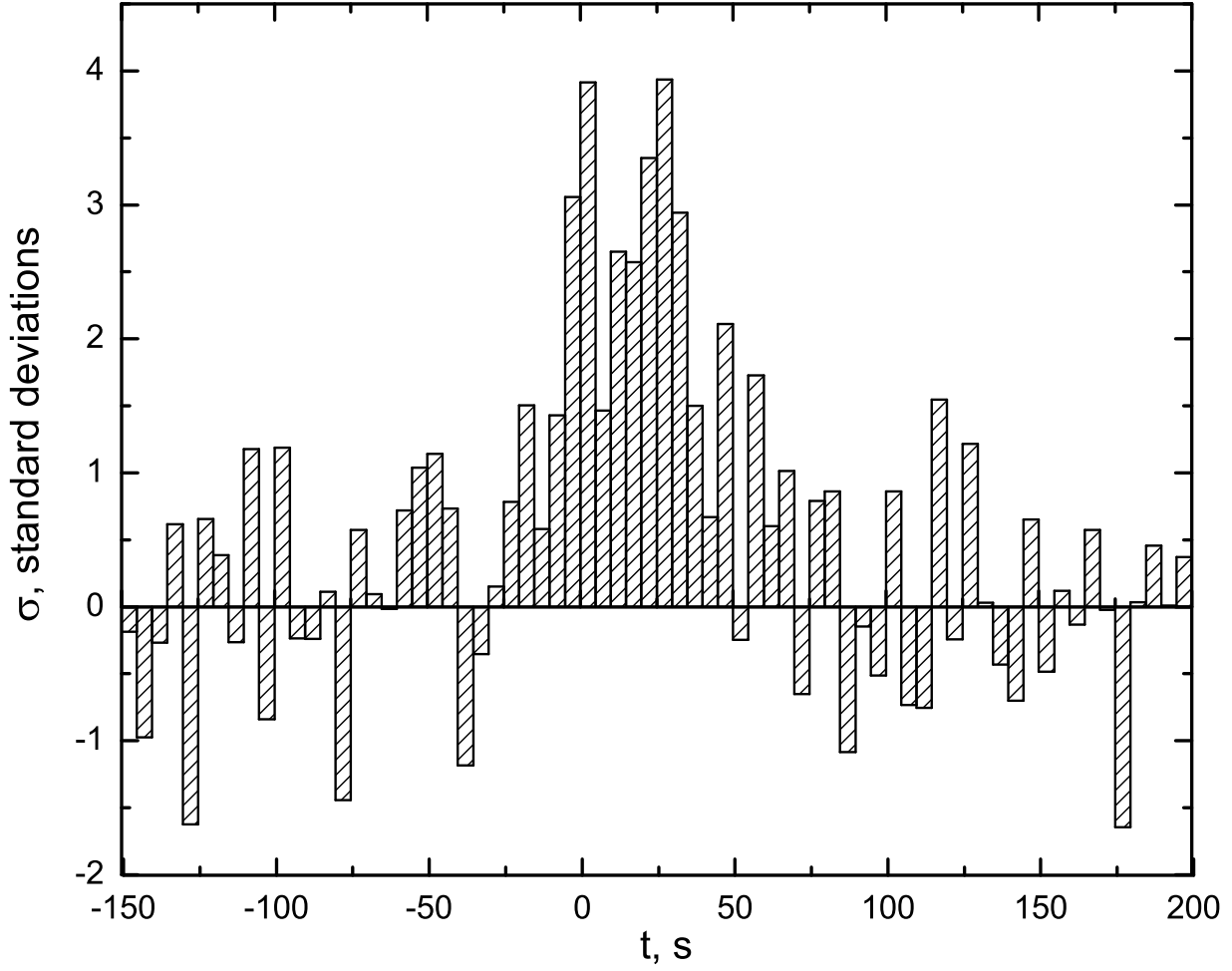


Fig. 5. Result of processing the light curve for GRB 060221. Time relative to the trigger T_0 is along the horizontal axis. The time resolution is 5 s. Significance in standard deviations is along the vertical axis. The time resolution is 5 s. Significance in standard deviations is along the vertical axis.

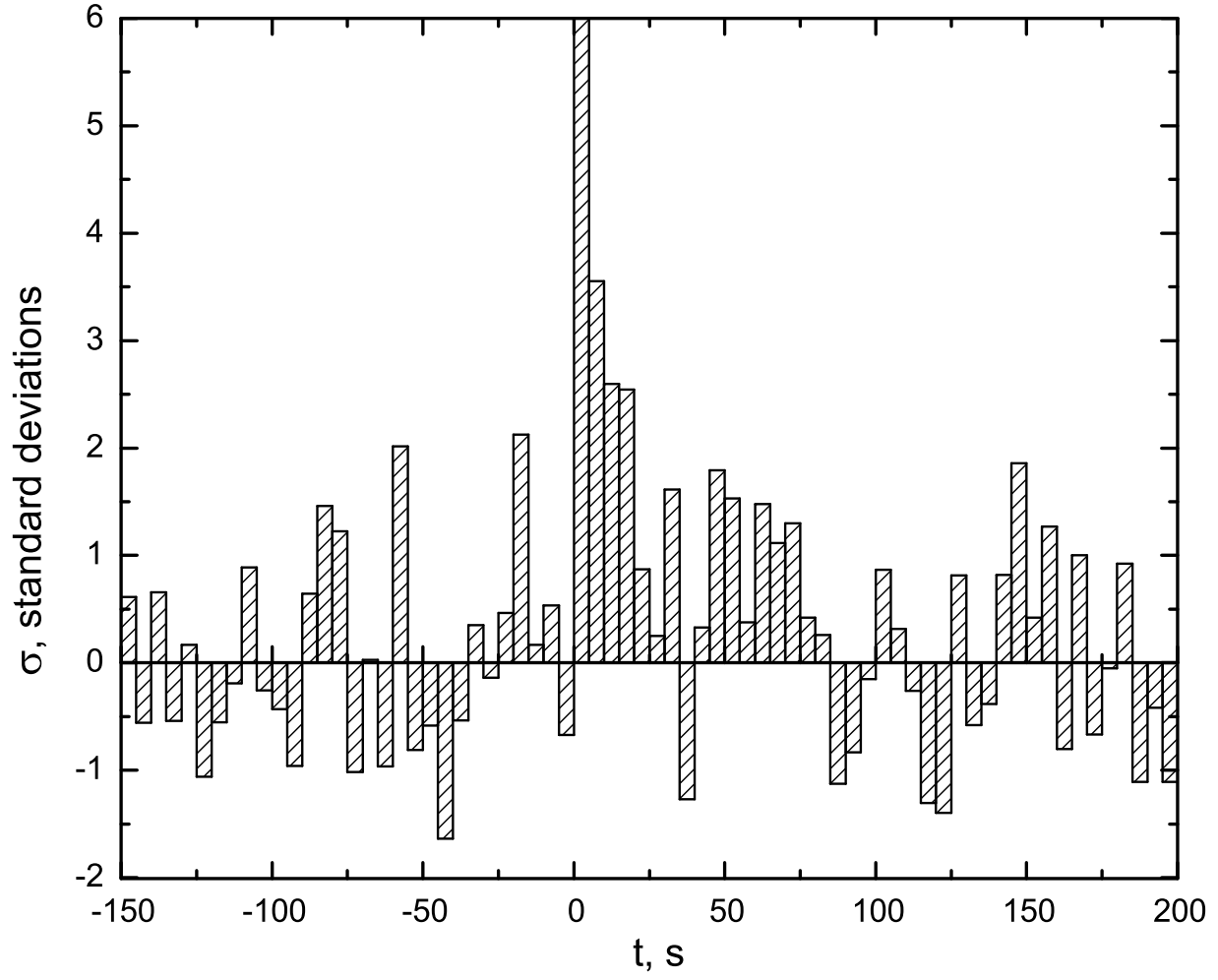


Fig. 6. Same as Fig. 5 for GRB 031214.

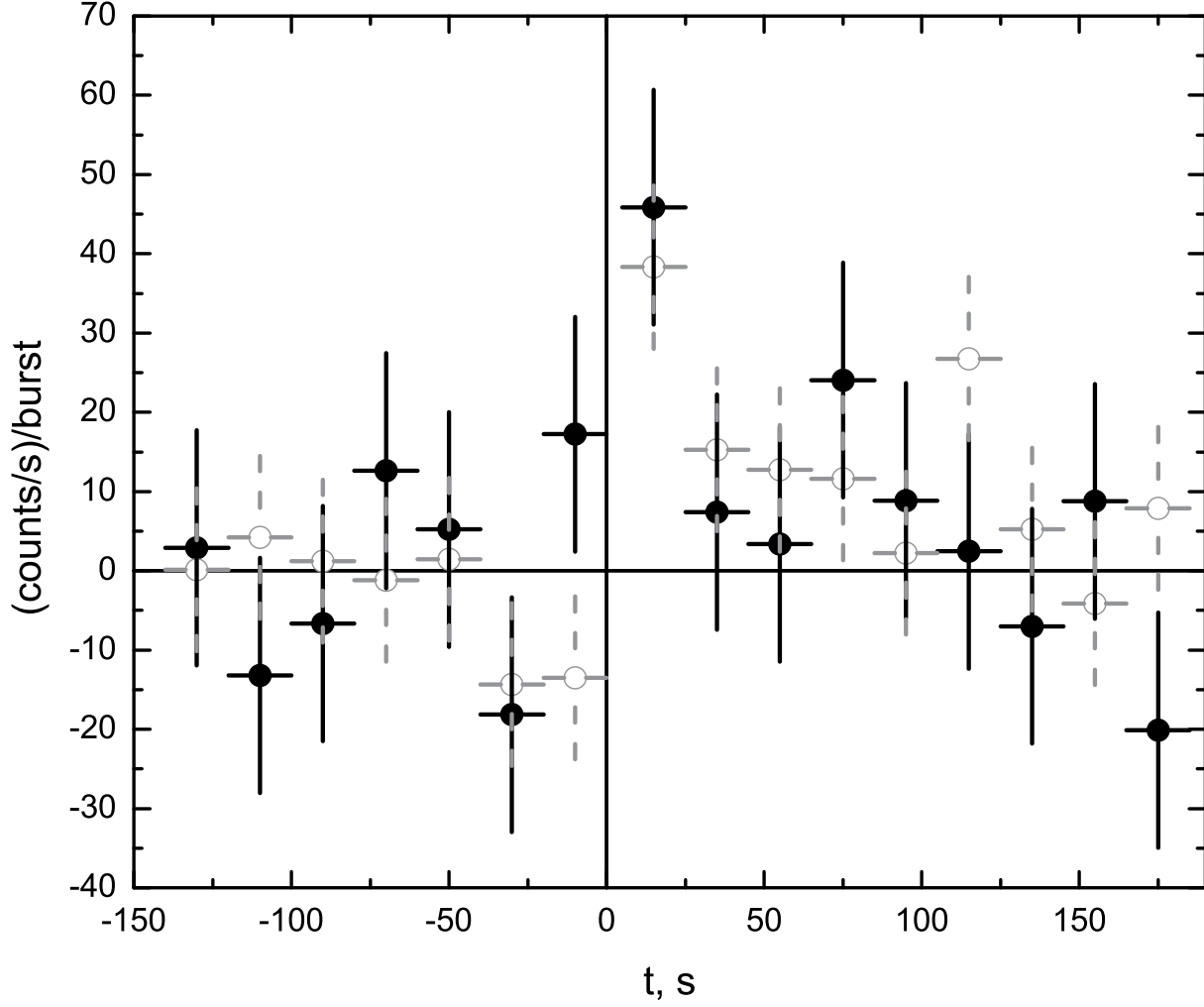


Fig. 7. Averaged light curve: the filled and open circles represent groups 1 (51 short confirmed GRBs) and 2 (105 unconfirmed short events from the catalog by Rau et al. 2005), respectively. The 1σ errors are given. The number of counts per second per event is along the vertical axis. The values corresponding to the primary peak outside the scale along the vertical axis.

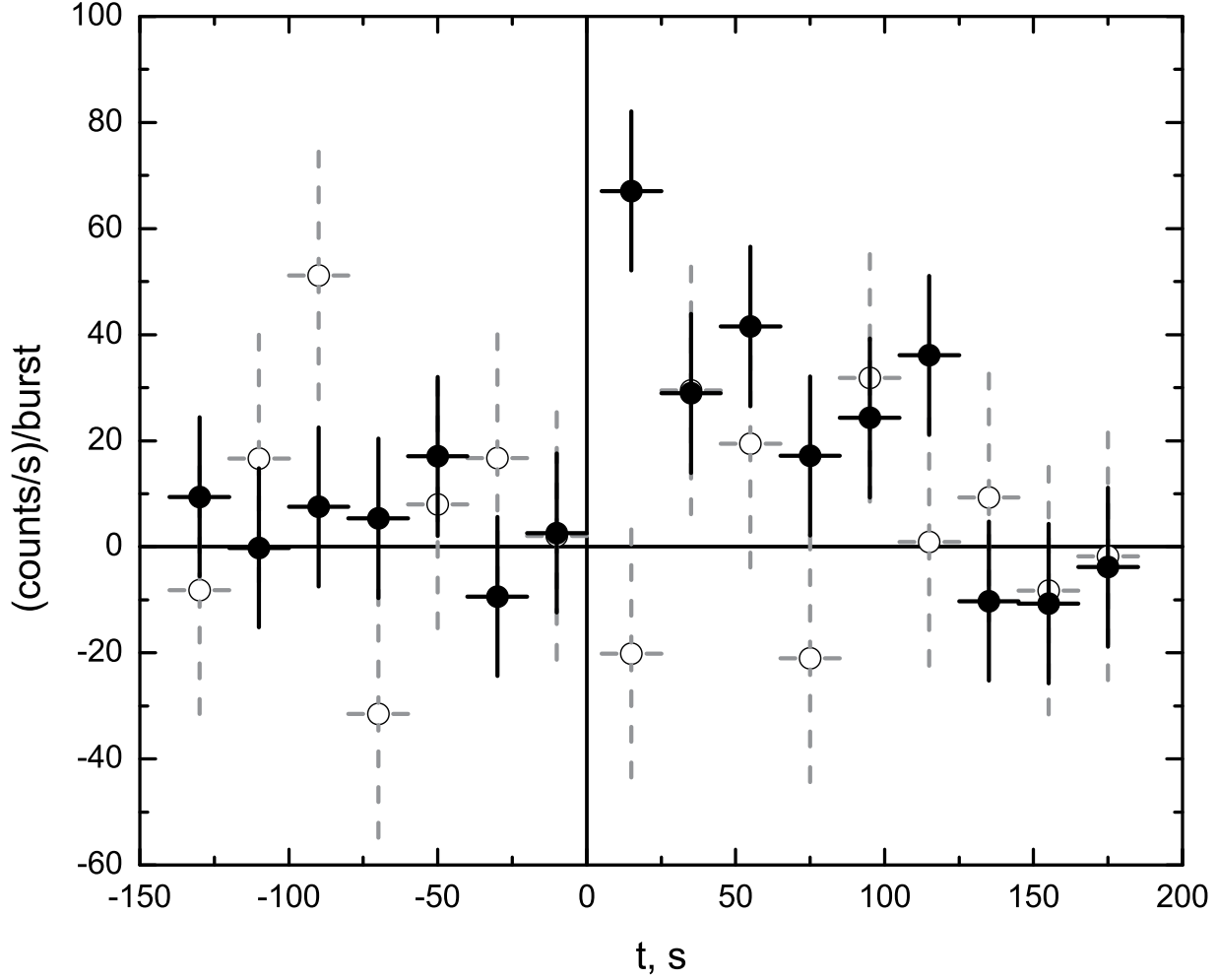


Fig. 8. Averaged light curve: the filled and open circles represent groups 3 (43 unconfirmed very short events from the catalog by Rau et al. 2005) and 4 (33 unconfirmed events related to triggers from charged particles), respectively. The 1σ errors are given. The number of counts per second per event is along the vertical axis. The values corresponding to the primary peak outside the scale along the vertical axis.

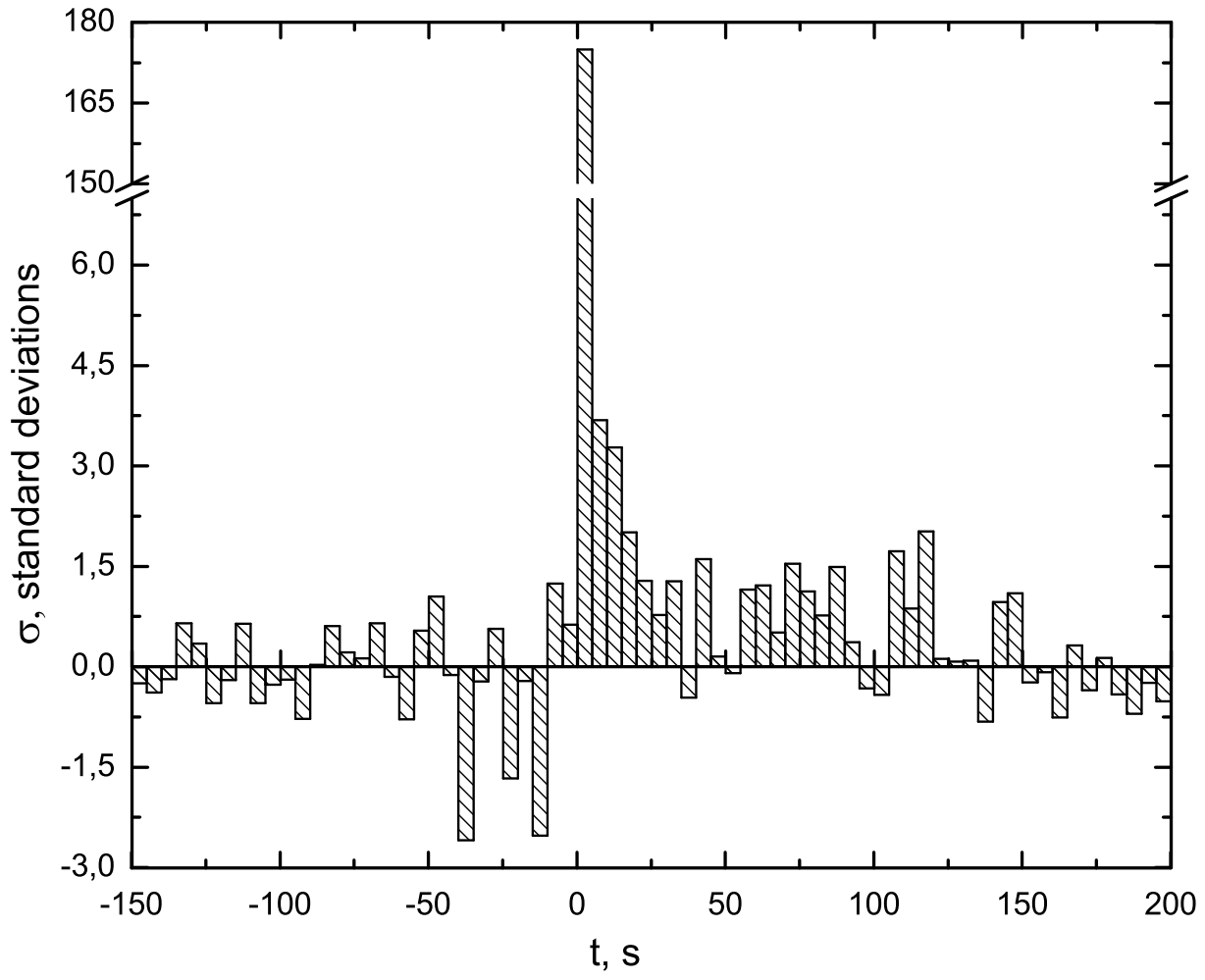


Fig. 9. Averaged light curve for the combined first and second groups of events. Time relative to the trigger T_0 is along the horizontal axis. The time resolution is 5 s. Significance in standard deviations is along the vertical axis.

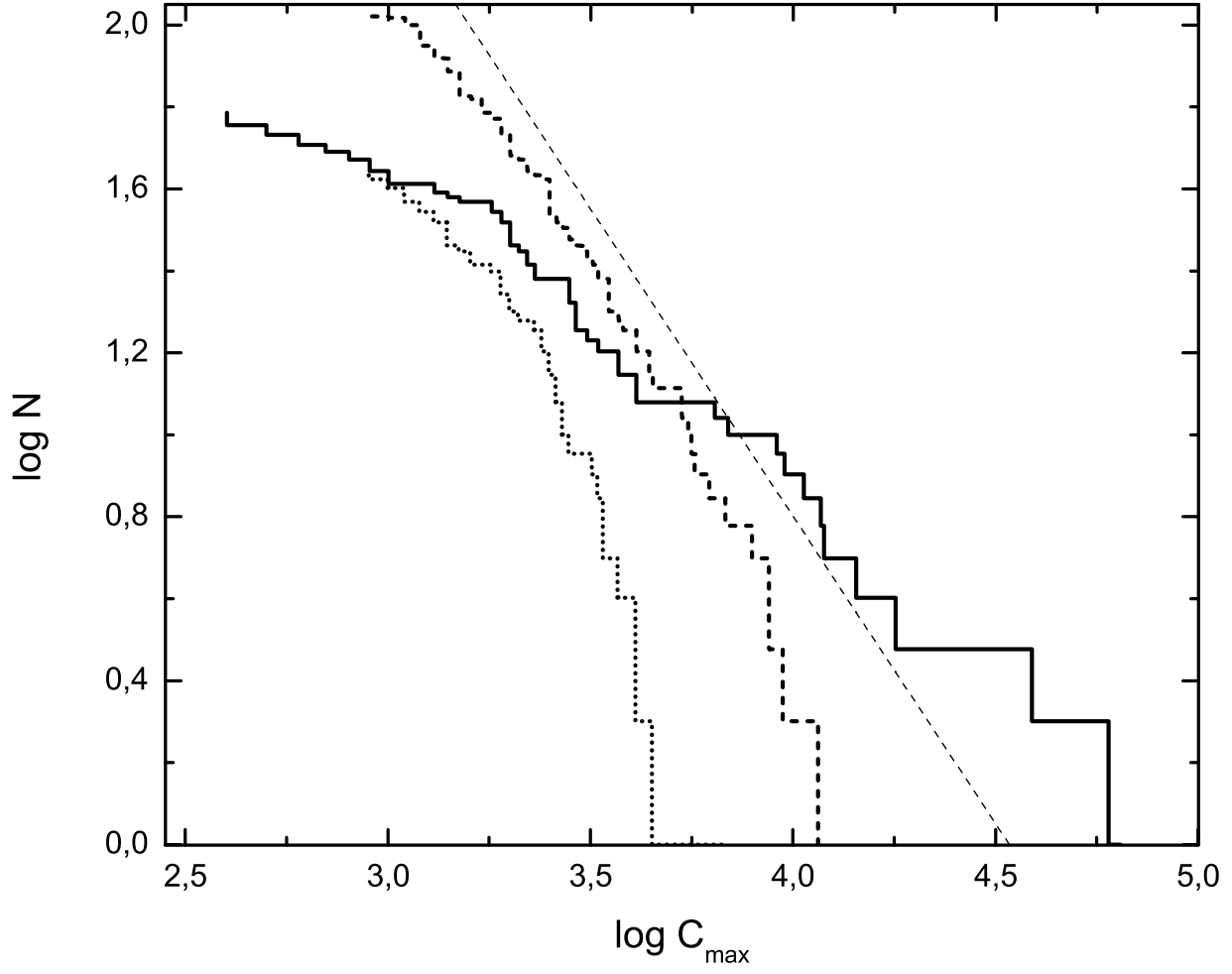


Fig. 10. $\log N - \log C_{max}$ distribution: the solid line represents group 1 (confirmed short events from our catalog); the dashed line represents group 2 (unconfirmed short events from the catalog by Rau et al. (2005)); the thin dashed line ($\log N - \log C_{max} \sim -3/2$) corresponds to a uniform distribution of sources in 3D Euclidean space.